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GIS Assessment of Regional Landslide Susceptibility, Mornington Peninsula Shire

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ABSTRACT

The Mornington Peninsula Shire extends from 40km to 100km south-east of Melbourne. Recently, the area has changed from a rural setting to increasing residential use. The Shire has a history of slope instability which can have significant impact on developments. This is complicated by a variable geology with at least five major geological formations. Council has relied upon local knowledge in their review of geotechnical assessments and the need for geotechnical investigations. The level of detail in the investigation reports is highly variable. In order to improve the process, Council wanted a more consistent method for assessing slope susceptibility and determining the level of geotechnical investigation required. A Geographical Information System (GIS) approach was selected. The GIS used a Digital Terrain Model with approximately 1 billion data points on a 1m grid manipulated to determine the slope and aspect. Other maps were developed that included cadastre, geology, geotechnical data, a landslide database, and four detailed localised landslide studies. By comparing the data with known areas of instability, a correlation was developed for each geological condition. Using the available data, the different zones of landslide susceptibility were determined. A susceptibility map for the Shire was then produced. Generally the GIS map has shown good agreement with geotechnical field and aerial assessments, except in locations of shallow rock or groundwater. The GIS is not a replacement for a geotechnical investigation but it does allow the Council to justify its insistence on a more detailed geotechnical investigation in certain areas.

Keywords: landslide susceptibility, slope analysis, Mornington Peninsula, GIS, LiDAR

1 INTRODUCTION

In 2000 the Mornington Peninsula Shire Council in Victoria, Australia, which covers an area of approximately 730 square kilometres, commissioned a study to conduct a shire wide assessment of 'landslide hazards'. During the 1980's and 1990's a number of landslides occurred in areas of the Shire, resulting in considerable damage to dwellings and in some cases resulting in their demolition. While some individual detailed studies were undertaken (Coffey 1999 and others), there were many areas across the Shire that were not covered. In addition, the Council was being presented with geotechnical reports that were insufficiently detailed to assess the landslide risk or susceptibility. Detailed field studies were considered to be too expensive and a GIS approach was adopted. The Shire commissioned a study to assess the extent of landslides areas across the Peninsula. The assessment included preparation of parameter maps for geology, cadastre, digital terrain, landslides and standing groundwater depths for inclusion in a Geographical Information System (GIS) of the Mornington Peninsula.

The assessment recommended that the maps be combined with a review of numerous consultants' reports to enable the development of a map that classifies the Shire into areas of 'high', 'medium' and 'low' landslide susceptibility. In accordance with AGS (2007), landslide susceptibility is defined as '*a quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area*'.

The study was then expanded to include the following:

- Make use of newly available photogrammetric digital data
- Review and include the Council and consultants reports
- Produce a database of slope failures
- Develop a logic sequence and algorithms for assessing the susceptibility

- Generate a landslide susceptibility map and corresponding required scope of geotechnical investigation for the Shire

At the time of the Shire commissioning the expanded assessment, the Australian Geomechanics Society released their guidelines for Landslide Risk Management in March 2007 (AGS 2007).

2 MORNINGTON PENINSULA GEOLOGY

The geology of the Mornington Peninsula and its relationship with slope stability is complex. There have been numerous papers and publications discussing the geology including Jenkin (1962, 1974, and 1988), Keble (1950), Gostin (1966), Neilson (1985, 1995 and 1999), Dennis, Price & Miller (1993) and Birch (2003). The Geological Survey of Victoria 1:63 360 maps of the area were used for the distribution of the geological units present [Cranbourne (1967), Sorrento (1967) and Western Port (1963)]. Gostin (1966) mapped the coastal geology in the Mornington to Frankston coastal zone.

The main geological units that are within the Mornington Peninsula, and the effect of slope stability on those units, are discussed below:

- *Ordovician siltstone/sandstone rocks* – Slope failures within the soils weathered from these rocks have been identified, especially in very steep areas.
- *Devonian Granitic rock* - Deep seated failure in slopes within the granitic rocks has not been recognized. However, the rocks are often highly jointed and prone to boulder failures in quarry excavations. Shallow failures in the weathered zone have also occurred.
- *Tertiary Basalts of the Older Volcanics* – Slope failures in these materials on hillsides are fairly widespread. It is the major source of slope instability on the Mornington Peninsula.
- *Tertiary Fyansford Formation (Balcombe Clay)* – The stability of this formation along the Port Phillip Bay coast and its relationship with slope failure of overlying geological formations is a major issue on the Mornington Peninsula coastline.
- *Tertiary Baxter Sandstone* – This formation is not regarded as a significant slope hazard, except when very steep. Generally failures of the Baxter Sandstone occur only as a result of failure surfaces in underlying geological units.
- *Quaternary calcareous sands and Calcarenite (Pleistocene)* –The variable degree of cementation in this deposit has a major impact on its stability as does the steepness, the height and degree of erosion by wind, rain and runoff.
- *Coastal dunes, beach ridges, swamp and alluvial deposits (Holocene)* – The dunes are not a major stability issue when undeveloped but can pose stability problems for construction if locally steepened. The swamp deposits can be soft and compressible but generally are located within creek confines.

There are other geological units, such as the Mt Martha sand beds, but these are minor and localised.

3 DIGITIZATION OF THE DATA

In order to develop the landslide susceptibility model it was necessary to digitise the available data into a GIS. The data sets included in the model are as follows:

- Geology Zones
- Identified Slope Failures
- Landslide Susceptibility Studies
- Digital Terrain Model

A brief discussion of the digitization of the data for each of the sets is provided in the following sections.

3.1 Geology Zones

As previously discussed, the geology of the Mornington Peninsula is complex. The Shire is covered by the three 1:63,360 geological maps, Western Port, Sorrento and Cranbourne, which were produced in the 1960's. The boundaries for the main geologies were digitised from the scanned maps. The different geologies defined for the study are discussed in Section 2.

The spatial accuracy of the geological boundaries is unknown, but it would be reasonable to conclude that they would be no better than 100m.

3.2 Identified Slope Failures

The study of aerial photography identified numerous landslides across the Mornington Peninsula. The landslides were classified into 'possible' to 'certain' from aerial photography and available reports. All of the landslides were included in the study. However, further field and intrusive assessment of the sites will be required to confirm if the possible landslides are 'actual' as well as to delineate the extent and features of the landslides.

3.3 Landslide Susceptibility Studies

There have been isolated studies of landslide susceptibility previously conducted for areas within the Mornington Peninsula Shire. These are:
- Ballar Creek, Mt Eliza – Coffey (1999)
- Tanti Creek, Mornington – Lane Piper (2010)
- Flinders Township – Lane Piper (2008)
- Hearn Creek, Mt Martha – Piper & Associates (1999)

The landslide susceptibility boundaries and criteria defined in those studies were reviewed to determine whether they were consistent with each other and the requirements of Council. These were able to be readily modified and the boundaries defined in the studies have been adopted in the current study. These studies have been used to validate the GIS model.

3.4 Digital Terrain Model

The Digital Terrain Model (DTM) for the model was initially based on photogrammetry (DSE CIP 2005-06) as it was the most comprehensive data available. This data was used for initial calibration of the susceptibility models and for development of the analysis code. While the photogrammetry data was fairly comprehensive it tended to 'average out' the slope gradients determined and therefore small sudden changes in gradient such as small cliffs, cut slopes and retaining walls were sometimes not clearly identified in the data.

As the study proceeded, more accurate LIDAR (LIght Detection And Ranging) data covering the whole of the Mornington Peninsula became available (DSE CIP 2006-07, 2007-08, 2008-09). This data, which was based on a 1m grid with 1 billion data points, was used for the final modelling.

The first step of adopting the LIDAR data for use in the susceptibility model was to determine its suitability for use and to assess the consistency between the different LIDAR data sets. While each data set was identified as having a vertical accuracy of +/- 0.1m, there were some discrepancies between co-located data sets of up to 2m. It was observed that most of the discrepancies occurred in heavily vegetated areas as a result of the vegetation. Where two sets of LIDAR data were available for a common point, the lower point was adopted (Geocomp, 2009). Single 'spikes' surrounded by lower points were also removed. Using these methods, the multiple LIDAR data sets were reduced to a single set of LIDAR data points with a 2m grid of approximately 250 million data points.

3.5 Other Input Parameters

Other input parameters such as rainfall, the depth of groundwater and bedrock, and coverage of vegetation were also considered for use in the susceptibility model. However, the data available for these parameters is for isolated widespread locations. The lack of data across the Shire rendered interpolation between locations as inaccurate and unreliable. Therefore, these parameters were not included in establishing the susceptibility model. However, the calibration of the model involved comparing it against known areas of instability. By comparing these landslides to the model, the typical conditions are implicitly being used in the model. In areas where there is higher than typical groundwater or shallower than typical rock, the model may be unrepresentative and consequently a geotechnical investigation for each site is still essential.

4 ESTABLISHMENT OF MODEL

The susceptibility analysis involves analysing the available data on an 8m grid over the whole of the Mornington Peninsula Shire. For each point on the grid, the following general methodology is adopted:

1. Determine if the point is within a previous study and if so adopt the susceptibility adopted in the previous study;
2. Determine if the point is within a known certain or possible landslide and if so adopt a 'high' susceptibility;
3. Determine the geology at the point;
4. Determine the maximum slope gradient of all LIDAR 2m grid points within a 6m radius. The 6m radius was selected to ensure that any sudden changes in slope between each 8m spaced analysis point were picked up. This ensures that the most conservative, i.e. steepest, slope in the vicinity of the point is used for the analysis and the impacts of nearby features such as cliffs, cuts and retaining walls are included.
5. Determine the average slope aspect of all LIDAR grid points within a 6m radius. This establishes the general orientation of the slope in the local area and allows directional bias to be used in the analysis;
6. Calculate the susceptibility based on the geology, slope gradient and aspect.

In order to appropriately quantify the landslide susceptibility of a site, and assign appropriate geotechnical investigation criteria to a site for a particular level of susceptibility, a classification system was developed to define the landslide susceptibility. This involves classifying areas into subjective zones of 'low', 'medium' and 'high' landslide susceptibility. Based on inspection of various landslide sites in the Peninsula and review of previous investigations, it was established that generally any two locations that have the same slope gradient, aspect and geology will often have the same susceptibility. The limits of the classifications are based on the extrapolation of the existing failures to similar slopes and geologies throughout the Shire.

A minor aspect bias was included to accommodate the slope direction taking into account the presence of Balcombe Clay and the exposure of a site. The Balcombe clay bias is a result of the down warp of the Manyung fault (Nielson, 1995). The exposure bias also allows for the fact that southern faces are normally wetter with lower evapotranspiration effects.

The landslide susceptibility classifications were defined in the analysis as follows:

- 'Low' Susceptibility (Green)
- 'Medium' Susceptibility (Yellow)
- 'High' Susceptibility (Red)

The limit between 'low' and 'medium' susceptibility has been defined as the point beyond which creep or minor slope movement is likely to occur, but not necessarily a significant slope failure, for the natural topography, excluding any site modifications. The limit between 'medium' and 'high' susceptibility has been defined as the slope for a particular geology beyond which slope failures have either previously occurred or are considered possible based on previous studies and aerial photography.

The critical issue in producing a susceptibility zonation plan is to determine the limits between various levels of susceptibility. The geology of an area is well defined at a location according to the geology map and so once the geology of a location is known, the most significant remaining variable is the slope gradient with all other factors being equal. Changes in the steepness of a slope affect the stability of a slope and therefore the susceptibility of a slope to landslides. It is therefore appropriate to say that for a particular geology there will be a critical slope gradient where the susceptibility changes from 'low' to 'medium' or 'medium' to 'high'.

In order to determine the appropriate slope gradient for the limits between different levels of landslide susceptibility, the data for slope gradient up-slope and down-slope of known landslide head scarps was plotted on a chart of frequency. A polynomial curve was then fitted to each data set. The slope gradient for the intersection of the up-slope and down-slope curves was then set as the susceptibility limit.

The slope distribution curves for the ‘medium/high’ susceptibility boundary for the Balcombe Clay impacted areas are shown in Figure 1. Similar curves for the ‘high/medium’ and ‘medium/low’ susceptibility boundaries were developed for each of the different geologies.

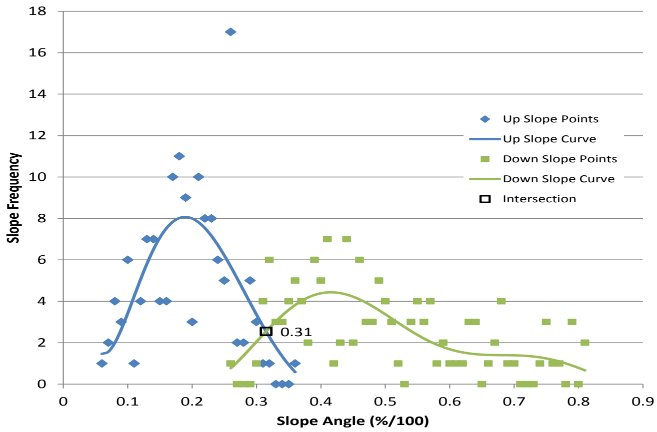

Figure 1: Slope Distribution Curve - Balcombe Clay Impacted Areas

Once the model was established it was verified against additional known landslides and areas of creep to confirm the validity of the model. For each geological area, localised susceptibility analyses were run using the model for a number of known landslides or previous field studies. The results of the localised analyses were compared to the actual locations of the landslides. In general, the model predicted the locations of the susceptibility boundaries with reasonable accuracy when compared to the locations of the landslide head scarps and creep zones.

5 RESULTS OF THE ANALYSIS

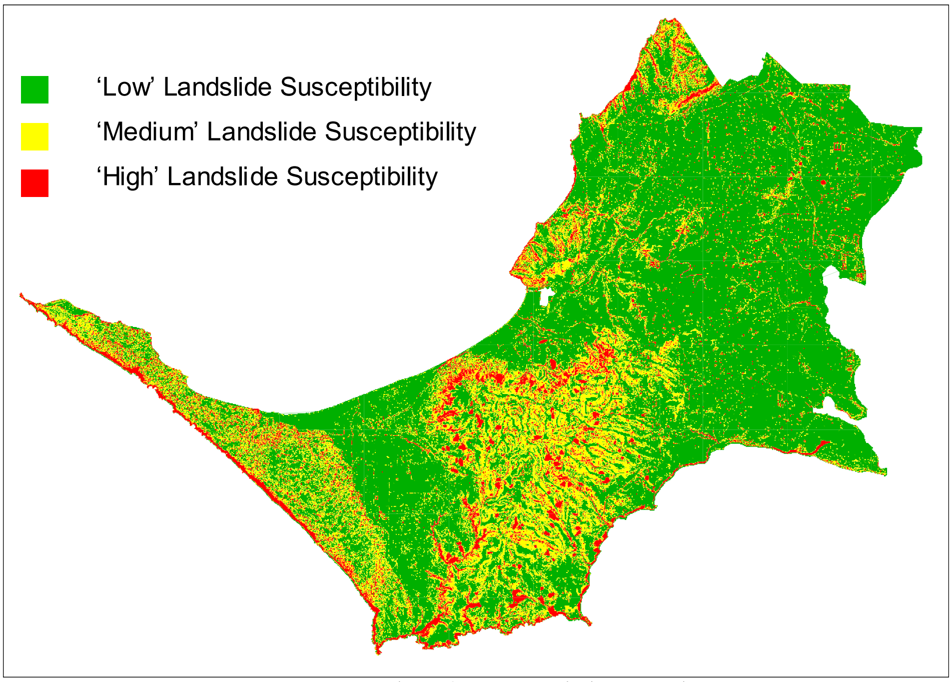

Figure 2: Results of Susceptibility Analysis

Once the relationship between geology, slope gradient and aspect as factors in landslide susceptibility had been developed and verified, it was possible to conduct a landslide susceptibility analysis for the entire Mornington Peninsula Shire. The analysis involved the assessment of approximately 15.6 million locations across the Shire. Polygons representing the various susceptibility zones were created resulting in a map of the various susceptibility zones across the Shire. A view of the output of the susceptibility analysis is shown in Figure 2.

6 LIMITATIONS OF THE ASSESSMENT

The assessment is primarily a desk–top review of the available information using existing literature, available data, reports and aerial photography. It is not an assessment of landslide hazard or landslide risk and a detailed geotechnical investigation is still essential for all sites. The landslide susceptibility modelling is based primarily on the geology and the slope gradients and aspects, although other issues are also considered. Other important factors such as the depth to the groundwater, the presence of a perched water table, vegetation and the depth to rock were not able to be considered in this assessment, and so the assessment is based on typical conditions occurring in the study area. Consequently if there is shallow bedrock or extensive trees in an area, the susceptibility assessment is likely to be conservative. Conversely, if there is a perched water table or shallow groundwater, the predicted landslide susceptibility zones may underestimate the actual landslide susceptibility for such locations. A geotechnical investigation is still required for each site and the results of an appropriate, site specific geotechnical assessment will always override this GIS study. The model can be refined as further detail on rock and groundwater depths become available in the future. The spatial accuracy of the GIS is limited to the accuracy of the 1:63,360 geology maps.

The assessment provides a rating for how susceptible a particular location is to landslides based on extrapolation of existing landslides. This assessment does not include areas that may be affected by landslide run-out or landslide regression.

7 CONCLUSION

This study has resulted in a map defining three different landslide susceptibility categories for the entire Mornington Peninsula Shire overlying the regional cadastre map. The study will assist the Shire to more confidently assess landslide susceptibility issues for development on the Mornington Peninsula and to define the areas requiring different levels of geotechnical investigation.

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REFERENCES

AGS (2007) “Landslide Risk Management”, Australian Geomechanics, Volume 42, No 1 March 2007
Birch W.D. (2003) “Geology of Victoria”, Geological Society of Victoria, Special Publication No. 23
Coffey Geosciences Pty Ltd (1999) “Landslide Zoning, Ballar Creek, Mt Eliza, Victoria”, Ref. M4164/1-AJ, 10 November 1999
Dennis, Price & Miller Pty Ltd, (1993) “Frankston Coastline Management Study”, November 1993
Department of Sustainability and Environment, “CIP 2005-06 Mornington Peninsula”, Photogrammetric Data
Department of Sustainability and Environment, “CIP 2006-07 Port Philip Western Port Project”, LIDAR Data
Department of Sustainability and Environment, “CIP 2007-08”, LIDAR Data
Department of Sustainability and Environment, “CIP 2008-09”, LIDAR Data
Geocomp Consulting Pty Ltd (2009) “Mornington Peninsula LiDAR Date Issues”, email to Lane Piper, November 2009
Geological Survey of Victoria “Cranbourne 1:63,360 Geological Map”, 1967
Geological Survey of Victoria “Sorrento 1:63,360 Geological Map”, 1967
Geological Survey of Victoria “Western Port 1:63,360 Geological Map”, 1963
Gostin (1966) “Tertiary Stratigraphy of the Mornington District, Victoria”. Proceedings of the Royal Society of Victoria, Volume 79, Part 2, No. 30, 21 September 1966
Jenkin, J.J (1962) “The Geology and Hydrogeology of the Western Port area” Undergr. Wat. Inves. Rep. Geol Surv. Vic., 5
Jenkin, J.J. (1974). “The Geology of the Mornington Peninsula and Western Port” Rep. Geol. Surv. Vic. 1974/3
Jenkin, J.J. (1988) “Mornington Peninsula. In Victorian geology excursion guide”, ed. I. Clark and B. Cook, Aust. Acad. Sci and Geol. Soc. Aust., Vic. Div.
Keble, R.A. (1950) “The Mornington Peninsula” Mem. Geol. Surv. Vic, 17
Lane Piper Pty Ltd (2008) “Geotechnical Assessment of Landslip Susceptibility and Investigation Zoning, Flinders Foreshore, Mornington Peninsula”, Ref 27005Report01.2, 24 January 2008
Lane Piper Pty Ltd (2010) “Geotechnical Assessment of Slope Stability, Tanti Creek, Mornington”, Ref 23019Report01.7, 30 March 2010
Neilson, J.L., (1985). “Preliminary Report on Geology and Ground Stability in a Coastal Area at Oliver’s Hill, Frankston”. Unpubl. Rep., Geol. Surv. Vict., 1985/75.
Neilson, J.L., (1995) “Geological Features relating to the Piping of Ballar Creek, Mt Eliza”, Report to Piper & Assoc.
Neilson, J.L., (1999) “Geology and Stability at Hearn Creek, Mount Martha”. Rep. to Piper & Assoc.
Piper and Associates (1999) “Slope Stability Analyses of Hearn Creek Banks, Mt Martha”, Ref 21006, 23 August 2000